U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Figure 1. Fort Hunter Liggett installed a lithium-ion battery to help mitigate demand charges and reduce PV curtailment. The battery was purchased with funding from the Army's Energy Resilience & Conservation Investment Program. *Photo by Lars Lisell, NREL.*

Considerations for Implementing PV plus Storage Systems at Federal Buildings and Campuses

Federal agencies have a long history of using solar photovoltaics and battery storage (PV plus storage) systems at remote sites where the technologies can offset costly diesel fuel. However, recent declines[1] in lithium-ion battery costs, along with changes in net metering policies and utility rate structures, are opening up opportunities for PV plus storage to be deployed cost-effectively at grid-connected sites.

When grid connected, storage systems can be deployed along with PV to maximize the economic value of the PV system and to support critical operations during grid outages (if configured and controlled appropriately). However, there are several reasons why PV plus storage systems are more complicated than PV alone, which this fact sheet aims to clarify.

Table 1. Value Provided by Distributed PV plus Storage

Use	Value
Utility bill cost reduction	Reduced demand charges, energy arbitrage
Revenue generation	Demand response, ancillary services
Resilience	Back-up power during grid outage

Estimating the Value of PV plus Storage

In general, PV plus storage systems can provide value by reducing costs, generating revenue, or providing resilience (Table 1). Cost reduction is achieved through utility bill management; for example, by increasing PV self-consumption, reducing demand charges, or using energy arbitrage. Revenue can be generated by dispatching the PV plus storage system during a demand response event or participating in ancillary services. Finally, these systems can provide back-up power to support critical operations during grid disturbances. PV plus storage systems are typically deployed for one of these purposes, but combining multiple value streams, or "value stacking," can increase the economics of PV plus storage systems.

Identifying a federal site's utility rate structure is an important step in evaluating the economics of a PV plus storage project, as utility bill cost reduction is typically a primary driver of behind-the-meter PV plus storage economics. PV plus storage systems are more likely to provide positive returns at sites with time-varying rates and/or high demand charges. Dynamic rate structures reward customers with flexible load profiles, allowing the PV plus storage system to maximize the value it generates. Other factors include the building's load profile and net metering policies.

Identifying the combination of value streams can be a complicated process. Additionally, access to grid service value streams may be constrained by access to wholesale markets. Participating in wholesale markets in regulated utility territories requires engaging with the utility. Projects may need to be coordinated through an aggregator who bundles many small distributed systems to form a network that meets market participation requirements. Federal sites can also face cybersecurity challenges when connecting to energy markets.

If the system's primary purpose is to provide resilience, utility rates and value stacking may be less important; instead, maintaining service through an electric service interruption would be the primary source of value provided by the system. The value of this resilience benefit can sometimes be hard to quantify and depends on the value of the load that is lost during the outage. A system installed for resilience also needs the ability to island (disconnect) from the grid. This requires additional equipment such as electrical isolation switches and multimode PV inverters, which can increase expenses by between 10% to 50% compared to the nonislandable system's cost.[2]

Sizing and Dispatching PV plus Storage

The primary purpose of the PV plus storage system dictates the system design, configuration, and cost. For instance, a battery intended to provide resilience may be required to maintain a minimum state of charge at any given time, limiting the

[1] *Revolution Now – Accelerating Clean Energy Deployment* (U.S. Department of Energy Office of Energy Efficiency and Renewable Energy, September 2016), DOE/EE-1478, *https://www.energy.gov/eere/downloads/revolutionnow-2016-update*.

[2] McLaren, Joyce, Seth Mullendore, Nicholas Laws, and Kate Anderson, *Valuing the Resilience Provided by Solar and Battery Energy Storage Systems* (National Renewable Energy Laboratory, January 2018), NREL/BR-6A20-70679, *https://www.nrel.gov/docs/fy18osti/70679.pdf*.

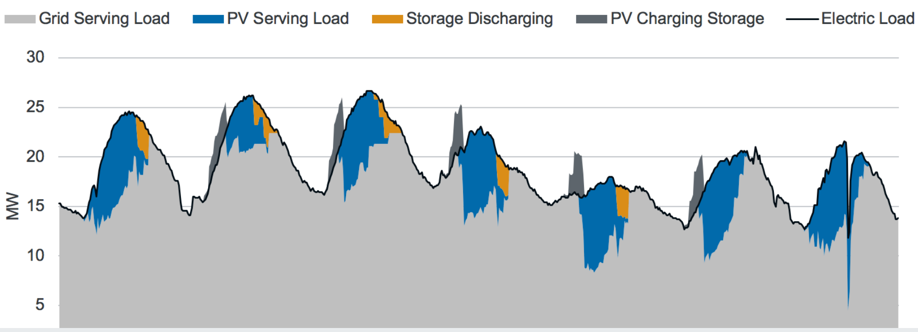

Figure 2. Dispatch of a PV plus storage system offsets energy costs and demand charges at a modeled federal site. *Image from Emma Elgqvist, NREL.*

Battery Storage Terminology Explained

- **Battery storage**: Technology that stores electrical energy in a reversible chemical reaction. Lithium-ion batteries are the most common technology for distributed (behind-the-meter) energy storage applications due to their performance characteristics and cost.
- **Dispatch**: The way that the battery is operated, including the times at which it is charged and discharged, and the depth of charge or discharge.
- **Degradation**: The decrease in the battery's capacity over time and through use.
- **Power**: Specified in kilowatts (kW) or megawatts (MW), the measure of the instantaneous output of a battery inverter.
- **Energy**: Specified in kilowatt-hours (kWh) or megawatt-hours (MWh), the measure of how much energy can be stored in a battery.
- **State of charge**: The battery capacity as a percentage of its maximum capacity at a given time.
- **Depth of discharge**: The battery capacity that has been discharged as a percentage of its maximum capacity.

ability to also provide other economic benefits. If the primary purpose is to aid in utility bill management, islanding capabilities may be unnecessary and the battery can be optimally sized and dispatched for cost savings.

The dispatch of the storage system also impacts its eligibility for federal tax incentives.[3] Batteries charged solely by PV are eligible for the 30% federal Investment Tax Credit (ITC); batteries charged by the PV system at least 75% of the time on an annual basis are eligible for a portion of the ITC.

Unfortunately, there is no one-size-fits-all system size or optimal dispatch strategy. Each system is unique based on the federal site's needs and site conditions. Figure 2 shows the dispatch of a PV plus storage system sized to minimize costs. The PV system (blue shading) is offsetting utility energy purchases (grey shading); however, the PV production decreases in late afternoon while the load is still high. The battery (orange shading) is dispatched during this time to lower the site's demand. The battery is additionally dispatched at times when the load is low (and demand charges can't be offset), but the cost of electricity is relatively high. The system sizes and dispatch strategy shown here are unique to this site's load profile and utility rate, and aren't necessarily applicable to other sites. One of many tools that can help determine optimal system size and dispatch strategy is NREL's REopt model.[4]

Contracting for PV plus Storage

The contract price and terms of a stand-alone PV system can easily be quantified by the energy it produces and the savings associated with the reduced cost of that energy compared to utility costs. The contract price and terms for a PV plus storage system are harder to define because (1) there can be multiple values streams associated with a PV plus storage system, (2) storage doesn't inherently generate any electricity, and (3) a storage system size is specified not only in power (like PV), but also in energy.

Federal entities have various vehicles for procuring PV plus storage systems, such as appropriations, energy savings performance contracts (ESPCs) and ESPC energy sales agreements (ESPC ESA), utility energy service contracts (UESCs), and power purchase agreements (PPAs). While the complexities of calculating the value of storage may make it difficult to identify the best procurement vehicle, industry is working with federal agencies to offer solutions for procuring PV and storage. For example, as of August 2018, Fort Carson in Colorado Springs, Colorado, was in the process of implementing a lithium-ion battery through an ESPC, and the National Archives in San Bruno, California, and United States Geological Survey in Menlo Park, California, were installing lithium-ion batteries through a PPA. Other sites such as U.S. Marine Corps Station Miramar and Fort Hunter Liggett (Figure 1), both in California, have pursued energy storage through appropriations.

For More Information

To learn more about implementing PV plus storage systems, contact Emma Elgqvist at the National Renewable Energy Laboratory, *Emma.Elgqvist@nrel.gov*. For FEMP assistance with your federal PV plus storage project, contact Rachel Shepherd at the Federal Energy Management Program, *Rachel.Shepherd@ee.doe.gov*, or visit *https://www4.eere.energy.gov/femp/assistance/*. ■

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FEMP Federal Energy Management Program

For more information, visit:
energy.gov/eere/femp

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[3] *Federal Tax Incentives for Energy Storage Systems* (National Renewable Energy Laboratory, January 2018), NREL/FS-7A40-70384, *https://www.nrel.gov/docs/fy18osti/70384.pdf.*

[4] "REopt Energy Integration & Optimization," NREL, accessed July 19, 2018, *https://reopt.nrel.gov.*